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Short Communication

Thermoelastic stress analysis for detecting wrinkles and associated resin pockets in polymer composites

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ABSTRACT

A thermos elastic stress analysis method is proposed consisting of an array of infrared measurement sensors used for evaluation the wrinkling defects and associated resin pockets in a fiber reinforced polymer (FRP) composite structure. Wrinkling or fiber waviness defects results when out of plane distortions occur in some or all of the composite layers of the laminate. The wrinkles result in significant reductions of mechanical properties in the composite structure. The method involves instrumentation and device for application of internal energy in the material such as transient or cyclic mechanical excitations. These external excitations are induced in a prescribed or measurable cyclic or transient function of time. Infrared measurements from the surface of the composite are synchronized with the applied excitation energy. The results are used to provide for a map detailing the inner wrinkle defects and associated resin pockets in the laminated composite structure.

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1. Introduction

Advances in the mass manufacturing of composites have made it possible to consider composites as a viable construction material for large structural components and assemblies. Recent examples include the composite fuselage and wing sections of the 787 Dreamliner or the Airbus A350, which will be the first Airbus aircraft with the fuselage and wing structures, made primarily of carbon fiber-reinforced composites. The challenge in manufacturing large composite structures results in the near impossibility to achieve parts with no manufacturing defects.

Fiber waviness is considered one of the most common types of defects that reduce the load carrying capability in composite structures (El-Hajjar and Petersen, 2011). Pre-cure and post-cure optical and ultrasonic techniques have been proposed for characterization with limited success. Ultrasonic methods are not reliable for detection of wrinkles due to the reliance on reflection and attenuation mechanisms that are not always significantly evident in the presence of the wrinkle defect. The waviness is not usually associated with impedance changes as compared with porosity which is more readily identified with the ultrasonic methods due to the large differences in impedance values between the resin, fibers and air voids. Industrial computed tomography scanners can be used to image internal flaws in composite structures but these currently have severe object size limitations.

In this study, we investigate the use of the thermos elastic stress analysis (TSA) approach (Rauch and Rowlands, 1993) for characterization of wrinkle defects in composite structures. In the TSA method, during cyclic loading and the presence of reversible adiabatic conditions, an infrared detector measures an un-calibrated TSA signal that can be correlated to the stress levels in the materials. Composite specimens are fabricated using a quasi-isotropic layup consisting of 32 plies of IM7 carbon fiber/epoxy prepreg and having waviness defects across the specimen width and at multiple locations. Specimens were tested at 5Hz at stress levels well below the failure stress of the material as damage initiation and propagation were not the focus of this study. The applied tensile stresses were maintained under 27 MPa to ensure the specimens remain in elastic range.

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2. Results

The contours produced from the TSA were analyzed and compared to the control specimens. Fig. 1 shows the TSA contours observed on the face of the specimen for the different waviness profiles under a mean tension stress (Elhajjar et al., 2014). Note that the observations were made on the side that is usually available for non-destructive evaluation. In these experiments, the width of the specimen is the field of view of the infrared camera. The results show a clear spike in the TSA signal near the waviness zones in all locations tested corresponding to the severity of the defect.

Compared to the control specimens, there was a clear incidence in the thermal emissions in the vicinity of the waviness zone. It is believed that the resin rich zone in the waviness profiles is responsible for the clear signatures identifying the waviness profile due to the thermos elastic constant differences between the resin rich areas and the other areas of the structure. While the method provides only indications from the resin pocket, assumptions on the underlying defect can be made. For example, a conservative assumption that all layers below the surface have the same aspect ratio as the resin pocket is one way to handle the subsurface anomaly.

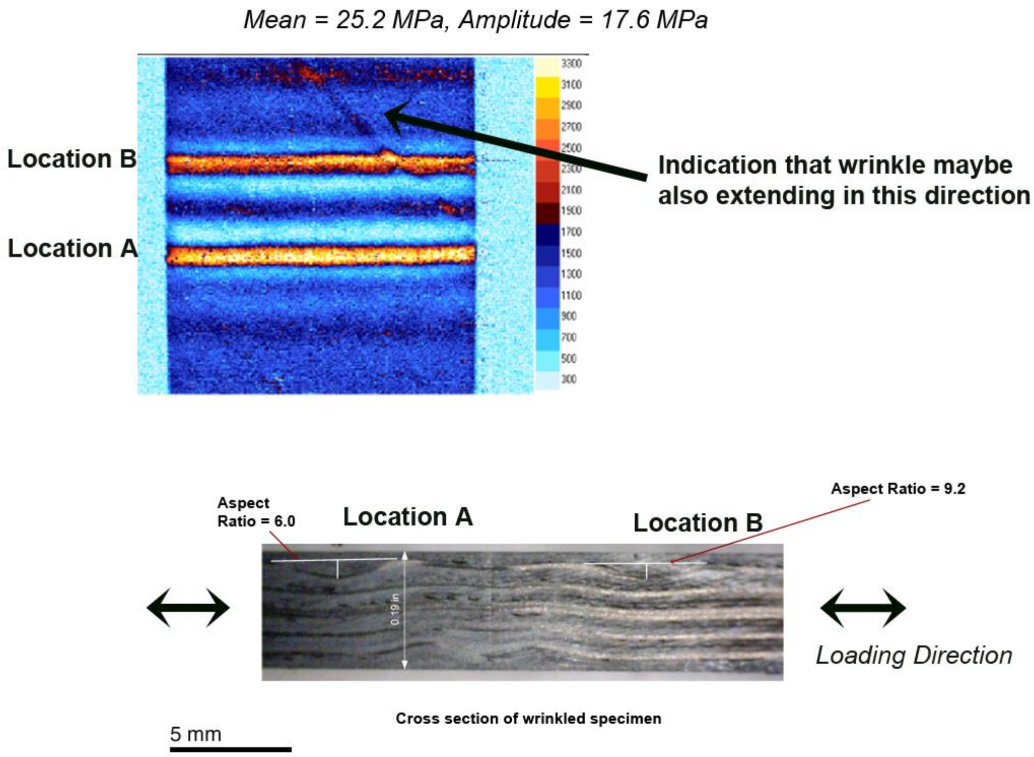

Fig. 1. TSA response on the surface of the specimen with respective cross-section.

3. Conclusions

The TSA approach proposed is linked to the excitation energy or stress state in the material. The TSA approach can provide indicators of structural integrity when wrinkle defects are involved. It does not require application of infrared radiation rather the system relies on relating the emitted IR to the structure's strain energy response under cyclic loading. Our demonstrations show that the present system is able to detect sub surface wrinkle and associated resin pockets. The system is capable of detecting wrinkles and associated resin pockets to an accuracy of the L/D ratio of less than 20 where L/D is the aspect ratio, defined as the length to depth ratio of the wrinkle wave. This range covers most wrinkles and associated resin pockets known to cause a degradation of load carrying capacity in composite structures.

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